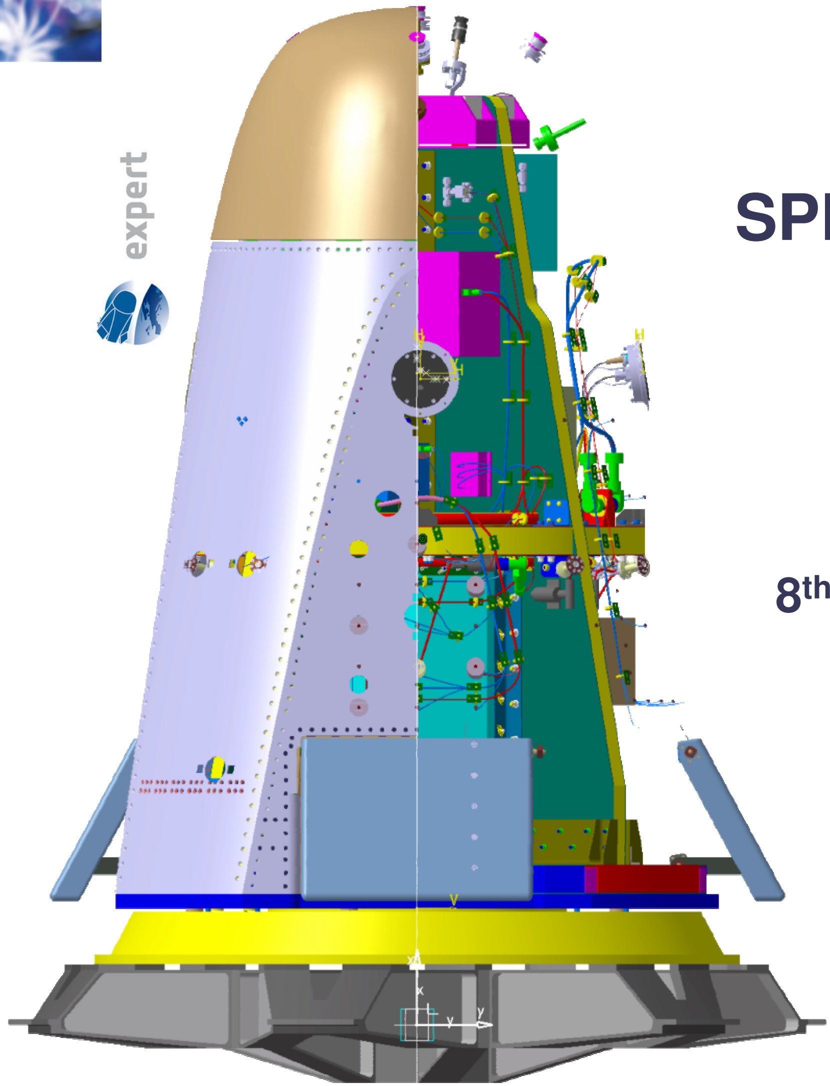
expert



OPTICAL EMISSION SPECTROSCOPIC EXPERIMENTS FOR IN-FLIGHT ENTRY RESEARCH

8th. INTERNATIONAL PLANETARY PROBE WORKSHOP

PORTSMOUTH, VIRGINIA

6-10 JUNE 2011

Sebastian Lein, Stefan Löhle, Georg Herdrich, Monika Auweter-Kurtz, Stefanos Fasoulas

Motivation

- Emission spectroscopic in-flight experiments provide data for validation of chemical/radiation models employed to simulate the loads on TPS systems
  - Validation of design tools

- Suitability of ground test facilities is limited
  - Multitude of relevant parameters can not be reproduced at the same time

→ In-flight experiments required

Content

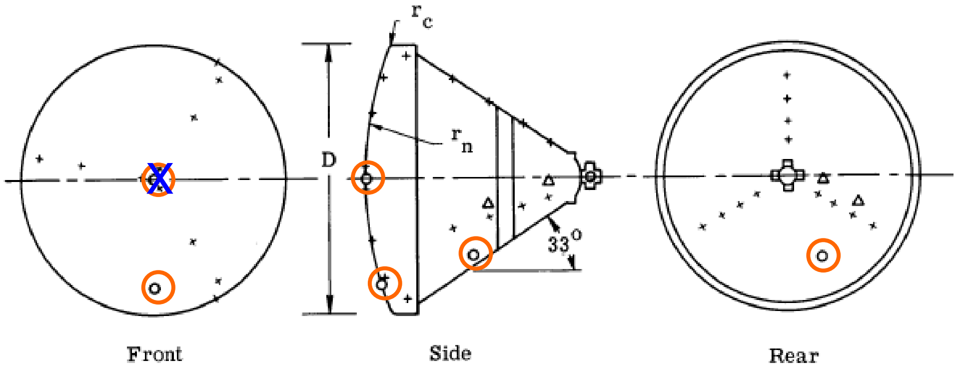
- Overview of past emission spectroscopic experiments for atmospheric entry
  - FIRE I & FIRE II
  - Bow Shock UV & UV Diagnostics Experiment
  - Airborne observation campaigns
    - Stardust
    - ATV1 Jules Verne
    - Hayabusa

- RESPECT / EXPERT
  - Experiment design
  - EXPERT mission
  - Expected results / post flight analysis

- Conclusions

FIRE - Flight Investigation of the Reentry Environment

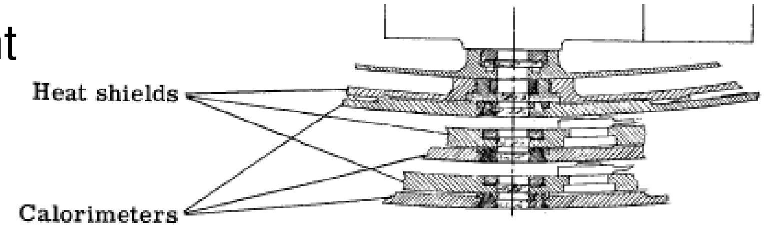
- 2 re-entry flights in 1964/1965 in preparation of the Apollo program
- Blunt, Apollo like shaped capsule
  - Nose radius: 0.935m, diameter: 0.672m / 0.630m / 0.587m
- Hyperbolic re-entry
  - FIRE I: v = 11.57 km/s, γ = -14.6°
  - FIRE II: v = 11.35 km/s, γ = -14.7°
- Instrumentation for radiation heat flux
  - 1 spectrometer system x
    - 200nm – 600nm (FIRE II: limited to 300nm – 600nm due to blocked mechanism
    - 4nm spectral resolution
  - 3 radiometer systems ○
    - 200nm – 4000nm



Cauchon, D. L., Radiative Heating Results from the FIRE II Flight Experiment at a Re-entry Velocity of 11.4 Kilometers per Second, TM X-1402, NASA, 1967.

FIRE - Flight Investigation of the Reentry Environment

- Layered heat shield
  - → Measurement periods in clean environment
  - flow undisturbed from erosion products
  - realized by 3 calorimeter layers



Cauchon, D. L., Radiative Heating Results from the FIRE II Flight Experiment at a Re-entry Velocity of 11.4 Kilometers per Second, TM X-1402, NASA, 1967.

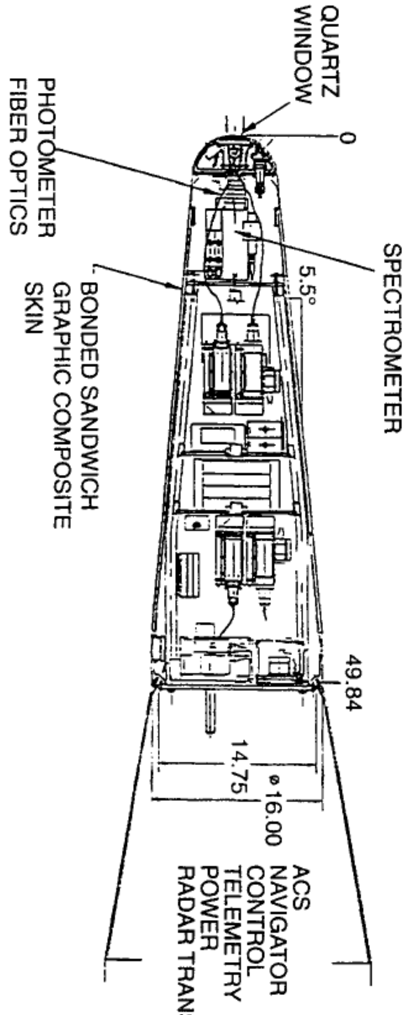
- Test case for coupled flow field/radiation simulation (Park, Merrifield/Fertig)
  - Rebuilding of total heat flux is rather successful, but limitations apply:
    - simulations show up to 90% of total radiation heat flux in VUV
    - →VUV measurements recommended
    - Absorption in boundary layer extremely sensitive to chemical composition
    - →TPS material characterization/ consideration of gas surface interaction (catalysis) required

Data Period	Altitude / km	Velocity / km/s
Fire I		
1	89.01 – 70.00	11.63 – 11.53
Fire II		
1	83.75 – 69.80	11.37 – 11.30
2	54.34 – 53.23	10.61 – 10.51
3	41.80 – 40.75	8.20 – 7.74

- FIRE II is considered one of most significant in-flight experiments

Bow Shock UV & UV Diagnostics Experiment

- Flight regime different to the hyperbolic conditions of FIRE
- Bow Shock UV (BSUV), 1990
  - measurement during ascent from 38km – 70km, v = 3.5km/s
- UV Diagnostics Experiment (UVDE), 1991
  - measurement during re-entry, structural failure at 62km, v = 5.1km/s
- Instrumentation (BSUV & UVDE)
  - Upper stage with nose radius of 0.1016m instrumented with:
    - 8 radiometers (different viewing angles, 0°, 30°, 50°)
      - NO γ, OH A-X and N_2^+ 1st. neg. band systems
    - NO filled CaF_2 window acting as VUV detector (O I 130.4nm + H I 121.5nm (only UVDE))
    - 1 spectrometer (stagnation point)
      - 200nm – 400nm
      - 1nm spectral resolution
- Numerical rebuilding successful for lower altitudes
- Triggered improvements (Kanne):
  - NO reaction rates
  - electronic excitation due to heavy particle collisions
- Allowed for validation of numerical models originally developed for hyperbolic entry

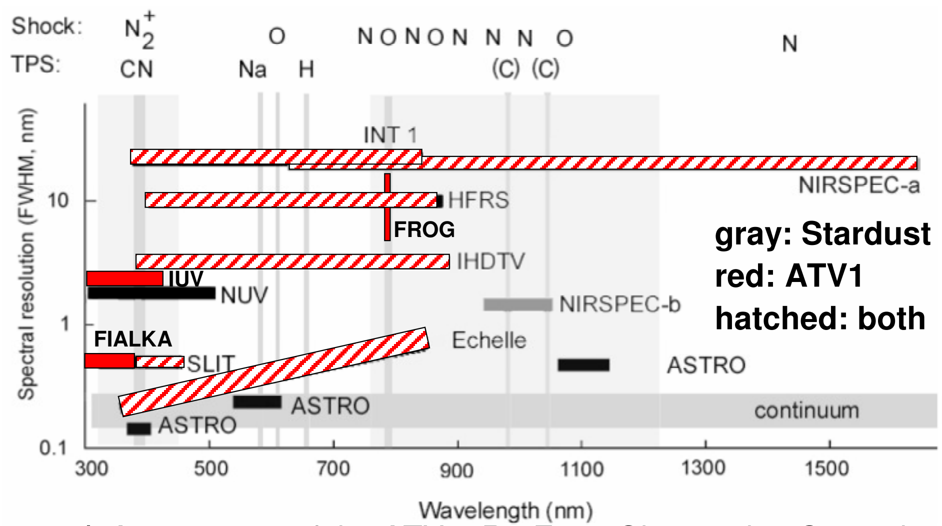


Erdman, et al, Measurement of Ultraviolet Radiation from a 5-km/s Bow Shock, *Journal of Thermo-physics and Heat Transfer*, Vol. 8, No. 3, 1994

Stardust, ATV1 & Hayabusa Airborne Observation

- Emerged from a lack of onboard instrumentation
- Multitude of spectroscopic experiments part of airborne observation campaigns
- Covering different spectral ranges/resolutions → various scientific goals
- Disadvantages:
  - Large distance to measurement object → loss of spatial resolution
  - Influence of atmospheric signal extinction, in particular for VUV
- Advantages:
  - Volume, mass, power consumption less restricted
  - Mechanical and thermal loads almost negligible

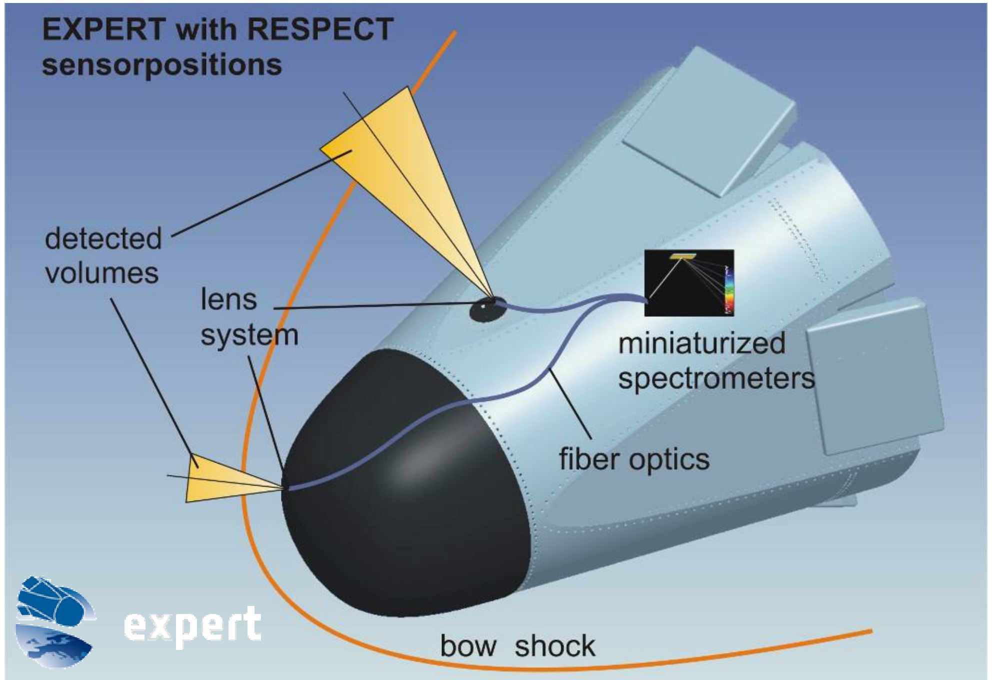
→ Allow for in-flight experiments not fitting in budgets or environment of re-entry vehicles



Lips, et al, Assessment of the ATV-1 Re-Entry Observation Campaign for Future Re-Entry Missions, 4th. IAASS Conference, Huntsville, AL, 2010

RESPECT - Re-Entry SPECTrometer

- 1. European spectrometer system for re-entry application
- Developed in the frame of the ESA EXPERT
- Goal: Build a database on **spectrally resolved emission** during re-entry
- **Comparison with coupled flow field/radiation codes**
  → achieve information about chemical/radiation models used (validation)



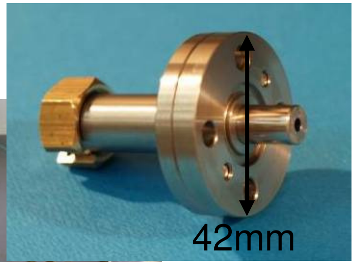
Sensor Head 1 (C/C-SiC nose):

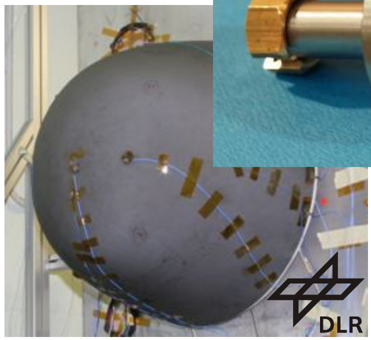
- Higher temperatures in the stagnation region
  → **more species observed**
  → more accurate statements on chemical models possible
- Detection of **erosion products** possible.
  (i.e. **active/passive oxidation**)

Sensor Head 2 (PM1000 panels):

- Examination of relaxation

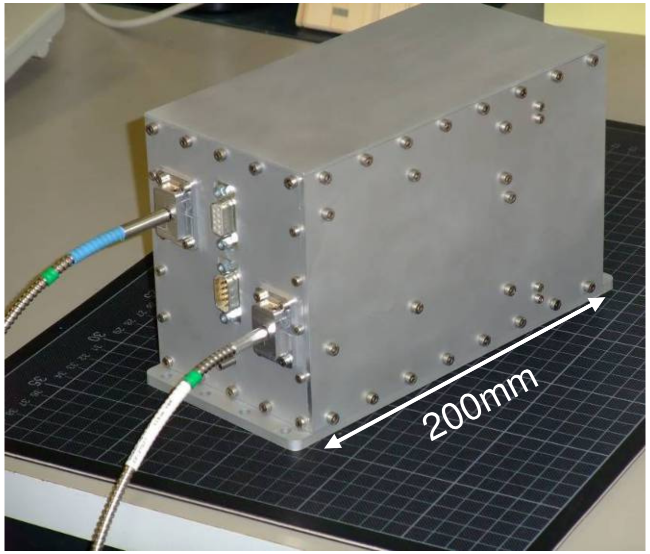
RESPECT sensor system





Sensor Head 1

Sensor Head 2



Fiber Optics & Sensor Unit

- Sensor system developed at IRS on basis of miniaturized spectrometer (OceanOptics S2000)
- Further electronics components: microcontroller for spectrometer control, data storage, communication & power conditioning
- Sensor heads individually designed based on the requirements of the TPS

<u>system parameters:</u>

mass: ≈2.3kg + harness
- ≈ 2.0kg SU
- ≈ 0.2kg SH1
- ≈ 0.1kg SH2

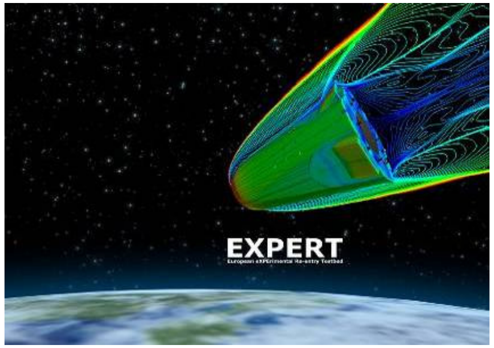
power consumption:
- ≈ 3.5 W

data interface:
- RS422 @115kbps
- 3082 bytes per spectrum

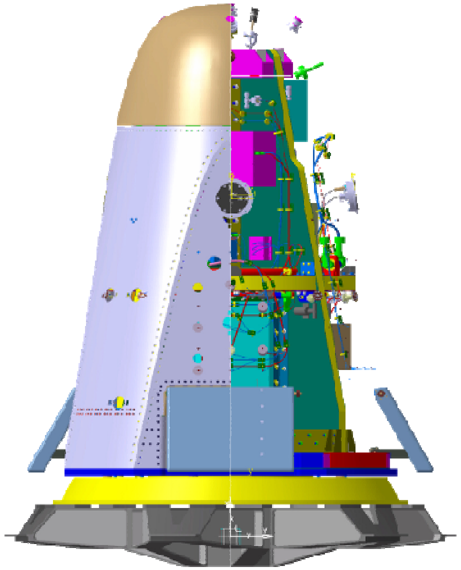
measurement spec.:
- ≈ 200 - 850nm
- FWHM ≈ 1.5nm
- sampling rate up to 15Hz

EXPERT - European eXPErimental Re-entry Testbed

- ESA project for technology demonstration and investigation of various phenomena related to atmospheric entry:
  - Real gas effects
  - Transition (APT-PAT, LTT)
  - Shock layer chemistry
  - Catalytic effects

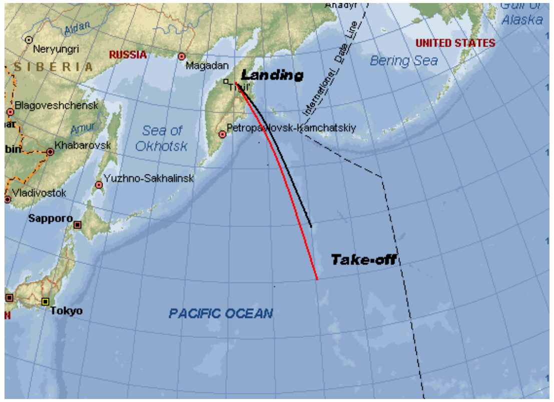


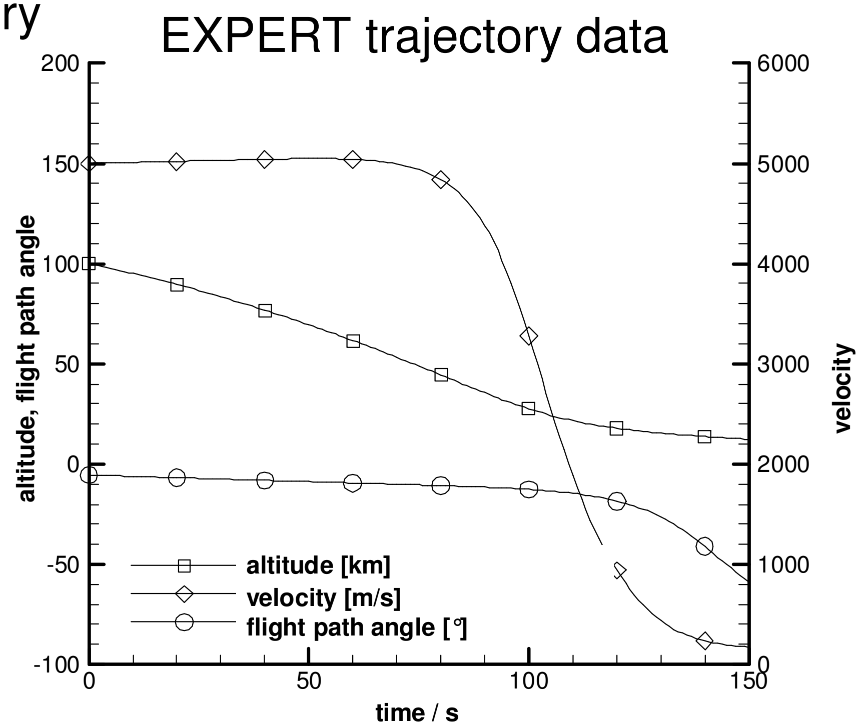
- Realization:
  - Ballistic capsule with 14 scientific payloads
  - Vehicle dimensions: 1.6 m length x 1.2 m diameter
  - Mass: 436kg
  - Nose radius: 0.55 m



EXPERT - Mission

- Launch in 2012 with Russian Volna rocket
  - Submarine launch in Pacific ocean
  - Parachute landing on Kamchatka peninsula
- Parabolic suborbital flight path
  - Re-entry: v_e=5 km/s, γ_e=-5,5°
- Measurement period covers whole trajectory
  - Payload activation prior to re-entry
  - Payload deactivation at ≈17km
- Trajectory similar to UVDE, but lower altitudes will be covered, too
  - EXPERT/RESPECT complements available set of spectroscopic data
    - FIRE: high-speed
    - BSUV: low-speed
- Further asset:
  - 14 different experiments in one flight





RESPECT – Post Flight Analysis

Calibration check & Sensor system inspection

Post processing of measured spectra

Link to EXPERT PLs and trajectory data

- cooperation -

URANUS flow field simulation

PARADE radiation simulation

Calibrated spectra

COMPARISON

Rebuilt spectra

Results:
- Species Identification incl. Erosion Products (if existing)
- Detection of PAT – APT
- Estimation of excitation temperatures
- Analysis of relaxation

Improvement/Validation of Numerical Models
- Statement on accuracy of current numerical models
  - Chemistry modeling (emphasis on oxygen)
  - Radiation modeling (required improvements in QSS modeling expected)
- Diffusion, chemistry and radiation modeling of erosion products (if existing)
- Test case definition for numerical tools

Results:
- Extraction of locally resolved plasma composition (e.g. particle densities, excitation temperatures, …)
- Analysis of relaxation

Initiation of new TRPs (e.g. QSS modeling)

Immediate impact on future re-entry vehicle design by increased reliability of design basis (numerics).

Conclusions

- So far, only a few emission spectroscopic in-flight experiments performed
  - FIRE I / FIRE II (1964/1965)
    - Hyberbolic entry
    - Nitrogen chemistry and radiation modeling
    - VUV, plasma wall interaction
  - BSUV /UVDE (1990/1991)
    - Low(er)-speed
    - NO reaction rates
- Complemented by RESPECT/EXPERT (2012)
  - O_2/NO
  - Extended wavelength range (200nm-850nm)
  - EXPERT incorporates 14 different scientific payloads
- Set of in-flight data available to validate numerical tools, but limitations apply
  - All experiments related to Earth re-entry
  - No VUV experiments
- Future Experiments (?)
  - VUV
  - Radiation ablation coupling
  - Other atmospheres (e.g. Mars, CO_2)